IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Borran, et al.
Title:	PARTIALLY COHERENT CONSTELLATIONS FOR MULTIPLE-ANTENNA SYSTEMS
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DECLARATION UNDER 37 C.F.R. § 1.132

Sir:

I, Callie M. Bell, hereby declare the following:

1. I am an attorney of record for United States Patent Application No. 10/671,346, filed on September 24, 2003.

2. Attached as Exhibit C is a true and accurate copy of the Proceedings of the IEEE International Symposium on Information Theory (ISIT) 2002 Conference printed from the webpage IEEE Explore. Exhibit C includes a Table of Contents for the Proceedings of the ISIT 2002 Conference that indicates a presentation by Mohammad Jaber Borran, Ashutosh Sabharwal, Behnaam Aazhang, and Don H. Johnson, titled <u>On Design Criteria and Construction of Noncoherent Space-time Constellations</u> occurred Monday June 30, 2002 in Lausanne, Switzerland (page XI). Exhibit C further includes a one- page summary of the presentation titled <u>On Design Criteria and Construction of Noncoherent Space-time Constellations</u> included at page 74 of the Proceedings of the ISIT 2002 Conference.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and believe are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Respectfully submitted,

Dated: July 8, 2008

By ________________

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Exhibit C

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Analysis of Turbo Codes

Decoding of Block Codes

On Design Criteria and Construction of Non-coherent Space-Time Constellations

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We consider a non-coherent communication system with M transmit and N receive antennas in a block Rayleigh flat fading channel with coherence interval of T symbol periods. We use the following complex baseband notation

$$X = SH + W, \tag{1}$$

where S is the $T \times M$ transmitted matrix, X is the $T \times N$ received matrix, and H and W are the unknown (to both transmitter and receiver) $M \times N$ and $T \times N$ matrices of the i.i.d. fading coefficients and additive noise terms from $\mathcal{CN}(0, 1)$. The transmitted symbols are also assumed to be power constrained, $\sum_{t=1}^{T} \sum_{m=1}^{M} \mathrm{E}\left\{|s_{tm}|^2\right\} = P$.

The capacity of non-coherent systems was studied in [1], where it was shown that at high SNR or when the coherence interval is much greater than the number of transmit antennas, capacity can be achieved by using a constellation of unitary matrices. However, at low SNR, or for small values of T (e.g., $T = 1$), unitary constellations are no longer optimal. The exact expression for the pairwise error probability of unitary constellations and the Chernoff upper bound are also given in [1]. However, these expressions appear to be intractable for the general case. Therefore, inspired by Stein's lemma [3], we propose the use of Kullback-Leibler [3] distance between distributions to approximate the exponential decay rate of pairwise error probabilities. The design problem will then be to seek constellations that have the largest minimum KL distance between the received distributions assigned to their elements (maximin code design). The resulting constellations coincide with the unitary designs at very high SNR or very low rates. But for high rate codes or at low SNR, different signal sets are obtained which show better probability of error performance.

The KL distance between $p_i = p(X|S_i)$ and $p_j = p(X|S_j)$, where S_i and S_j are two different $T \times M$ matrices from the constellation, can be calculated as

$$\begin{aligned} \mathcal{D}(p_i \| p_j) = \; & N \operatorname{tr}\left\{(I_T + S_i S_i^H)(I_T + S_j S_j^H)^{-1}\right\} - NT \\ & - N \ln \det\left\{(I_T + S_i S_i^H)(I_T + S_j S_j^H)^{-1}\right\}. \end{aligned} \tag{2}$$

Examining (2) shows that the KL distance consists of two parts. For example, for $M = 1$, (2) reduces to

$$\begin{aligned} \mathcal{D}(p_i \| p_j) = \; & \left[\frac{1+\|S_i\|^2}{1+\|S_j\|^2} - \ln\left(\frac{1+\|S_i\|^2}{1+\|S_j\|^2}\right) - 1\right] \\ & + \left[\frac{\|S_i\|^2 \|S_j\|^2 \sin^2(\angle S_i, S_j)}{1+\|S_j\|^2}\right], \end{aligned} \tag{3}$$

in which, the first part is due to having different magnitudes (lying on different spheres in $\mathbb{C}^T$), and the second part is due to the angle between the points (lying on different one-dimensional subspaces of $\mathbb{C}^T$). This decoupling property suggests partitioning the signal space into subsets of concentric spheres and using only intrasubset and intersubset KL distances in the maximin problem.

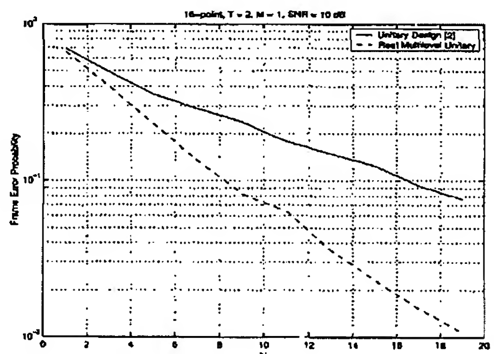

Fig. 1: Frame error rate comparison of 16-point real constellations

The unitary space-time codes of [1] have exponential encoding and decoding complexity. In [2] suboptimal unitary constellations with very low encoding and decoding complexity are proposed. In this work, we use the low complexity designs of [2] as the subsets of our multilevel constellation. The resulting 16-point real constellation for $T = 2$ and SNR = 10dB is a two level constellation, with 4 points on the inner circle and 12 points on the outer circle. The error rate performance of this constellation is simulated for different values of N and compared with the corresponding constellation proposed in [2]. The results are shown in Fig. 1. As we see, by using multilevel constellations (which use contributions from both parts of the KL distance) instead of single level unitary constellations (in which the first part of the KL distance is always zero), the performance of the non-coherent systems can be significantly improved. Moreover, the new constellations have a decoding complexity similar to the low complexity designs of [2].

References

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[3] T. M. Cover and J. A. Thomas, *Elements of Information Theory*, Wiley Interscience, 1991.

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